

# **A STUDY OF THE UPPER LEG COMPONENT TESTS COMPARED WITH PEDESTRIAN DUMMY TESTS**

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## **ABSTRACT**

The upper leg component test proposed by EEVC WG17 is one of the tools for the evaluation of upper leg injuries in pedestrian accidents. Meeting the injury criteria set by EEVC for the upper legform impact test is one of the biggest challenges we can find in the reports. This problem was studied in previous papers using simulation models or reconstruction of pedestrian accidents.

The POLAR pedestrian dummy was constructed by HONDA R&D and GESAC INC., and some crash tests were conducted with it. The object of this study is to compare EEVC WG17 upper legform impact test conditions for utility vehicles with the full dummy test results. To reconstruct the deformation resulting from tests using the POLAR, the impact energy for the EEVC upper legform impact test should be decreased. Even the upper limit of 700J is too high.

Accident data analysis shows that the pelvis is the body part injured by the bonnet leading edge of the utility vehicle. So the impact force should be mainly considered for the evaluation of the bonnet leading edge performance.

## **INTRODUCTION**

To consider the evaluation of bonnet leading edge (B.L.E.) performance, the injuries connected with the B.L.E. that are found in accident data are analyzed again. This data indicates that upper leg injuries, including pelvis injuries for utility vehicles, mainly consist of pelvis injury. The POLAR pedestrian dummy was constructed and the crash tests were conducted with it for both the automobile type and the utility

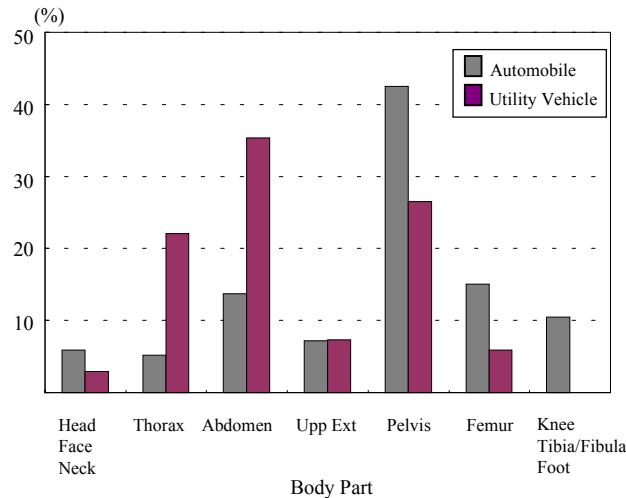
vehicle type. The results show that for the utility vehicle type the pelvis contacts the B.L.E. directly and the femur injury data is smaller than the pelvis data. The EEVC upper legform impact test is said to evaluate the risk of femur and pelvis injury but the same criteria are adopted. The pelvis injury is determined by the acceleration or the force in side impact, not by the moment.

Some previous papers studied the proper test energy with EEVC upper legform impact test and the estimation energy in that test procedure was considered too severe. In this study the reconstruction method using the EEVC upper legform impact test is conducted simulating the dummy test results. To estimate the test energy, the simulation with FEM POLAR model and 3D FEM vehicle models is conducted and other energy cases are performed to reconstruct the dummy test deformation, too.

This paper is paying special attention to the upper leg injury inflicted by the utility vehicles' B.L.E. and outlines the accident data analysis, full dummy test results and the consideration of proper test conditions for the EEVC upper legform impact test.

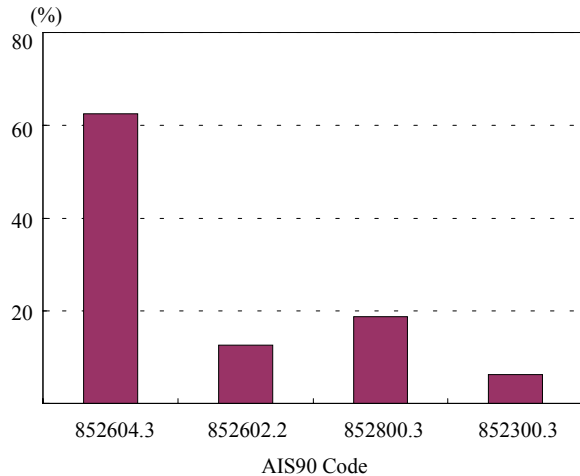
## **ACCIDENT DATA ANALYSIS**

The EEVC upper legform impact test is the evaluation method for vehicle B.L.E. aggressiveness, so the injury cases at B.L.E. are analyzed with the two data bases, Pedestrian Crash Data Study (PCDS by NHTSA) and Hannover Medical University Accident Research Unit (A.R.U.) data. The number of AIS2+ injuries inflicted by the B.L.E. is 221 and the number for the upper leg (pelvis and femur) injuries is 110, around 50% of the total B.L.E. injuries.



**Figure 1. Distribution of injury part at bonnet leading edge**

Figure 1. shows the distribution of body parts injured by the B.L.E.. It shows the injury distribution is depend on the vehicle type. For the automobile type, both pelvis injuries and femur injuries occur but for the utility vehicle type, the pelvis injury is more important than the femur injury. In PCDS, all injuries are described with AIS90 code and this helps to understand the detail of the injury. Figure 2. shows the details of pelvis injuries with AIS90 code. It shows the most frequent AIS90 code is 852604.3, which means pelvis fracture of any one or combination and open, displaced or comminuted injury.



852604.3: Pelvis  
Fracture, with or without dislocation, of any one or combination open/displaced/comminuted

852602.2: Pelvis  
Fracture, with or without dislocation, of any one or combination closed

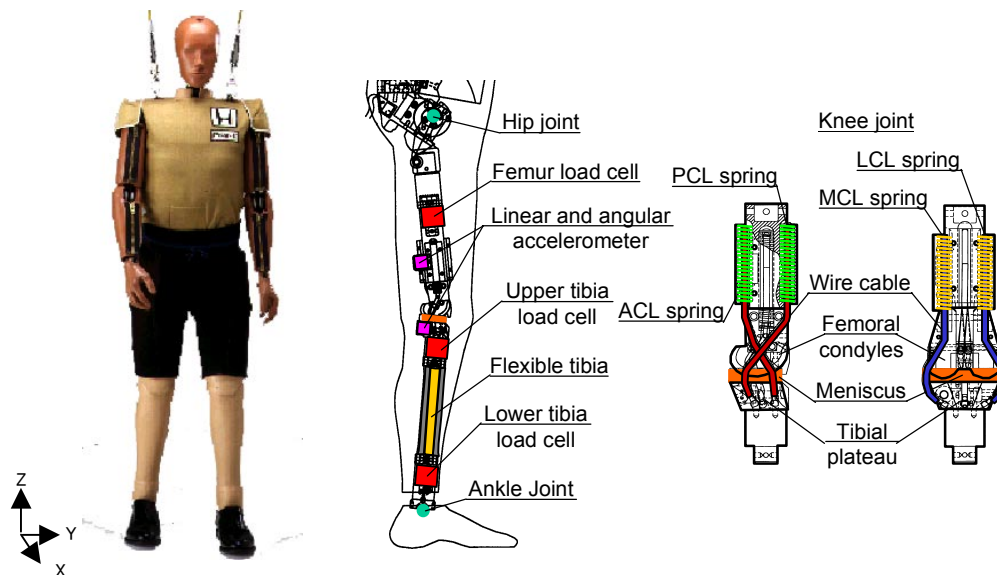
852800.3: Sacroiliac fracture with or without dislocation

852300.3: Symphysis pubis separation (fracture)

**Figure 2. Distribution of AIS90 code of pelvis injury for utility vehicle**

## PEDESTRIAN FULL DUMMY CRASH TEST

Honda R&D and GESAC INC., are since 1997, developing a pedestrian dummy for pedestrian protection [1][2] and the latest version is used in this study. Figure 3. and Table 1 show the overview of

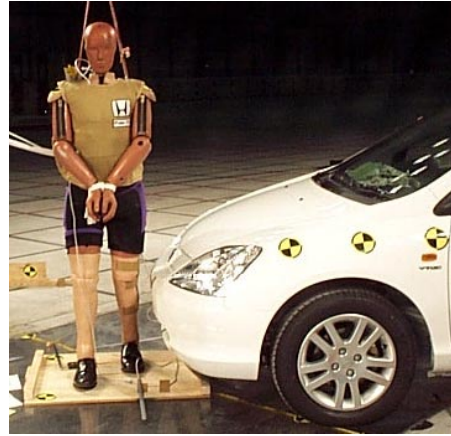


**Figure 3. POLAR and the schematic diagram of its lower limb**

**Table 1. Measurement list of POLAR**

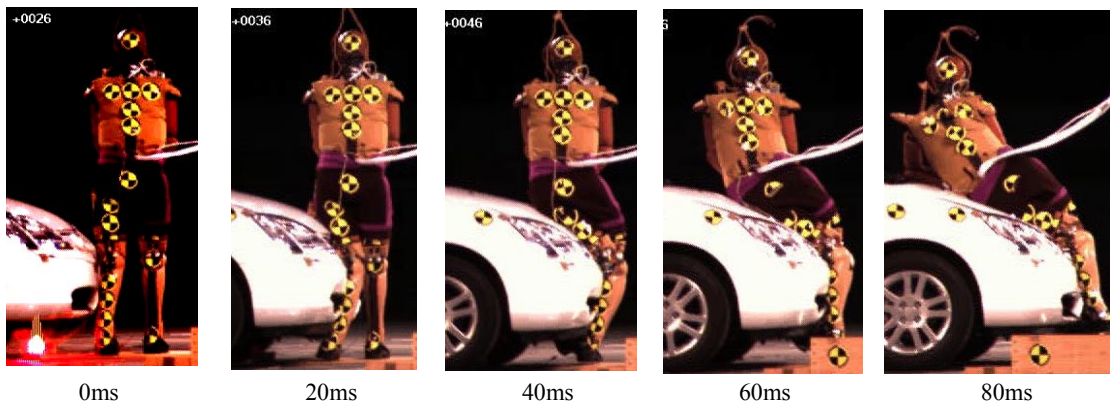
Part	Measurement	Direction	No. of CH
Head	Acceleration	X,Y,Z	3
Neck	Upper Load Moment	Fy,Fz,Mx	3
	Lower Load Moment	Fy,Fz,Mx	3
	Fore Sprig Load	Axis	1
	Aft Spring Load	Axis	1
Thorax	Acceleration	X,Y,Z	3
Pelvis	Acceleration	X,Y,Z	3
Femur (Left Leg)	Load Moment	Fy,Fy,Fz,Mx	4
	Acceleration	Y	1
	Angular Acceleration	X	1
Tibia (Left Leg)	Upper Load Moment	Fy,Fy,Fz,Mx	4
	Lower Load Moment	Fy,Fz,Mx	3
	Acceleration	Y	1
	Angular Acceleration	X	1

POLAR and the measurement channels. The inspection and the performance of POLAR are described by Akiyama et al. [3]

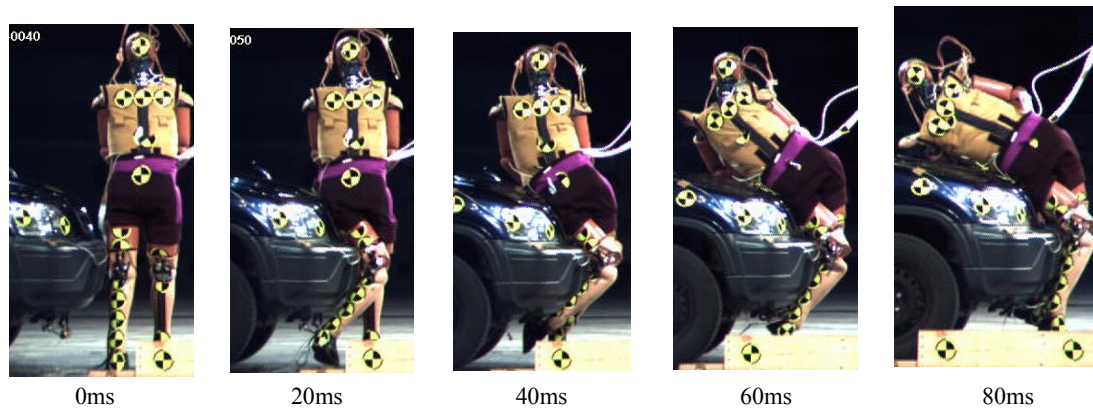


**Figure 4. POLAR setting at the crash test**

POLAR is positioned so that, its pelvis is in front of the vehicle center, its direction is lateral to the vehicle, its legs are forward and aft, the arms are put on the front side and are bound at the wrists. The crash tests are conducted with two different front shapes, the automobile type (Type-A) and the utility vehicle type (Type-B). The vehicle velocity is 40 km/h. Figure 4. shows the overview of the test setting.



**Figure 5. Mode of POLAR in crash test for automobile**



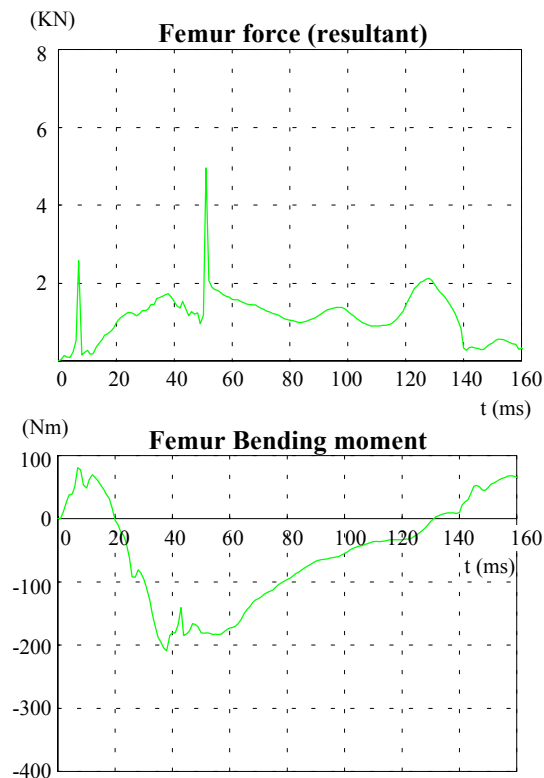
**Figure 6. Mode of POLAR in crash test for utility vehicle**

Fig.5 and Fig.6 show the mode of femur and pelvis for each vehicle type. For Type-A, the B.L.E. mainly contacts with the femur and the pelvis rides on the bonnet. On the other hand, for Type-B, the B.L.E. hits the pelvis directly and the femur contacts with the front grill and the bumper. So the main body part which gets the external force from the B.L.E. is the pelvis.

The measurement points in the POLAR femur and pelvis are the femur force ( $F_x$ ,  $F_y$ ,  $F_z$ ) and moment ( $M_x$ ) (using the load cell) and the pelvis acceleration ( $G_x$ ,  $G_y$ ) (using the accelerometer). Figure 7. and Figure 8. show the measurement results for each vehicle type. The POLAR does not have a load cell in its pelvis so for reference the pelvis acceleration times the pelvis mass(13.68kg) is used. The maximum deformation at the femur contact point for Type-A is 48.09 mm and at the pelvis contact point for Type-B it is 14.4 mm

#### EEVC UPPER LEGFORM IMPACT TEST

The EEVC upper legform impact test is conducted for the Type-B vehicle in order to compare it with the

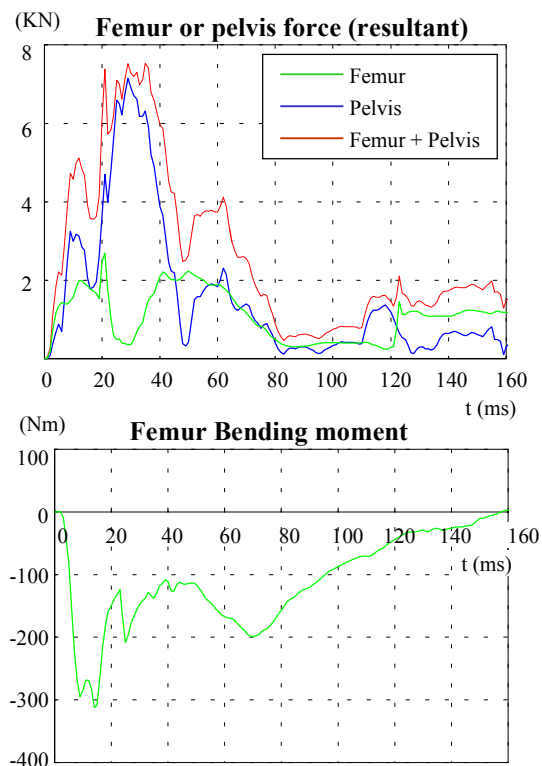


**Figure 7. Test results of femur force and bending moment for automobile**

POLAR test result. Here the impact point is the same as the point where the POLAR pelvis contacts and the deformation is maximal. Table 2. shows the test conditions from the EEVC WG17 look-up graph. The impact energy is 1095J from the look-up graph, so the upper limit, 700J, is adopted. Table 3 shows the test results. The deformation at the impact point is 27 mm, which is larger than the POLAR test deformation, 14.4 mm. The reason of this difference is that the test energy, 700J is considered to be higher than that of the POLAR test.

Matsui et al. [4] conducted the reconstruction tests of pedestrian accidents using the EEVC upper legform impact test. In this study the reconstruction tests of the POLAR test are conducted to consider the proper impact conditions for the EEVC upper legform impact test. The test conditions of the POLAR tests are precise and the pedestrian motion data exists so they are helpful to consider the proper impact test conditions compared with the actual accident data.

The impact test conditions are from the film data of the POLAR test except for impact energy. The impact energy is estimated using the simulation result. The



**Figure 8. Test results of femur or pelvis force and femur bending moment for utility vehicle**

**Table 2. EEVC WG17 proposed upper lrgform impact test conditions**

Type - B Vehicle		Impact Position lateral measurement from vehicle center line (mm)	Impact Velocity (Km/h)	Impact Angle (deg)	Impact Energy (J)	Impactor Mass (Kg)
B.L.E. Height (mm)	Bumper Lead (mm)					
891	176	120 Right side	40	33.4	Upp limit 700 (1095)	11.36

**Table 3. Results of EEVC WG17 proposed upper legform impact test**

Max. Deformation (mm)	Force (N)			Bending Moment (Nm)		
	Lower	Upper	Total	Upper	Middle	Lower
27	4273.3	7397.1	11670.4	633.4	903.5	910.0

**Table 4. Test conditions for reconstruction test**

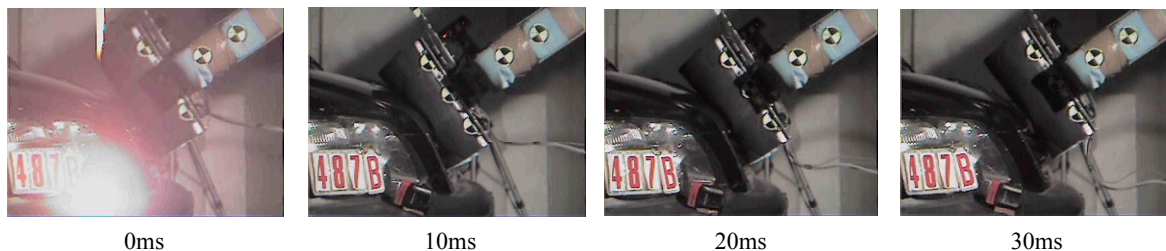
Test No.	Impact Position lateral measurement from vehicle center line (mm)	Impact Velocity (Km/h)	Impact Angle (deg)	Impact Energy (J)	Impactor Mass (Kg)
1	120 Right side	32.0	33.4	386.7	9.76
2	120 Right side	40.1	33.4	607.3	9.76
3	120 Right side	36.7	33.4	508.7	9.76

**Table 5. Results of reconstruction test**

Test No.	Max. Deformation (mm)	Force (N)			Bending Moment (Nm)		
		Lower	Upper	Total	Upper	Middle	Lower
1	14.0	3157.8	4604.8	7762.6	456.6	618.6	600.9
2	26.0	3755.9	5983.6	9739.5	544.7	766.8	779.9
3	17.1	3374.9	4919.1	8294.0	506.0	684.9	672.7

FEM model of POLAR is researched [5], and the same crash simulation as the POLAR test is conducted with it using a 3D FEM vehicle model. Konosu et al. [6] method is adopted for impact energy estimation, that is only the normal contact force and penetration of pelvis and femur are used to calculate the impact energy. Other impact tests are conducted to find the reconstruction condition as a parameter of energy. The

impact point is the same as where the POLAR pelvis contacts the B.L.E. and the deformation is maximum. The impact velocity should be around 40 km/h which is similar to the POLAR test, but the minimum weight of the upper legform impactor is 9.79kg so the impact velocity is modified. Table 4 shows the test conditions and Table 5 shows the results for each case. Figure 9. shows the mode of the upper legform and it keeps

**Figure 9. Mode of EEVC impactor in impact test for utility vehicle**

contact around 25 ms.

From Table 5., the proper energy to reconstruct the POLAR test result is found at around 400J. The energy from EEVC WG17 look-up graph, 1095J is much higher than this result and the upper limit energy, 700J, is also too high.

## DISCUSSION

1. From the crash test with POLAR, the femur measurement values are low because the impact force mainly comes from the pelvis impacting the B.L.E. for Type-B. And this result is similar to the actual accident data. The pelvis is the mainly injured body part for Type-B B.L.E. accidents. For Type-A, both pelvis and femur injuries occur at the B.L.E. so the evaluation methods for both parts are needed. But for Type-B B.L.E., the evaluation of pelvis injury should be mainly considered.

The injury mechanism of the pelvis being a mass and the femur with a long shaft is considered to be different but EEVC WG17 proposal uses the same test device and the same injury criteria. This is a problem. Many researchers described the evaluation parameter for the pelvis injury in side impact study. Cesari et al.(1982) [7] proposed cadaver tolerance with impact force, Tarriere et al.(1979) [8] reported pelvic fractures occurring at pelvic accelerations. Viano et al.(1989) [9] found the lateral compression was a good correlate to pubic rami fracture, and Zhu et al.(1993) [10] reported the average force was a good predictor of pelvic injury.

In the side impact dummy, the pelvis injury risk is evaluated using force and acceleration. Dr. Lawrence, TRL [11] described that for the EEVC upper legform, the peak bending moment relates to the risk of femur fracture while the risk of pelvis fracture is more related to the peak force.

From the accident data analysis, it was found that many pelvis injuries have fractures of many parts and comminuted injury. They are considered to occur under impact force, not bending moment.

Only the impact force should be adopted as the criterion for the evaluation of the utility vehicle B.L.E. using the EEVC upper legform impact test.

2. It is difficult to estimate the proper impact energy for the upper legform impact test using the POLAR test result. The crash simulation result is used for the estimation. Many previous papers using rigid body pedestrian models and 2D vehicle models are reported. In this study a FEM model of POLAR and a 3D vehicle model are used and the calculation is conducted by the same condition as the POLAR test. Figure 10. shows the structure of lower limb and the overall view of the calculation model. The energy for the EEVC upper legform impact test is estimated from this result. The estimation method of Lawrence [11] and Konosu et al. [6] is adopted,

- (1) The extent to calculate the energy is between the time  $t_1$  and  $t_2$ . Here  $t_1$  and  $t_2$  mean the cross point at 40% of the peak force in pelvis and femur force time histories. ( Lawrence method )
- (2) Energy is calculated with only the normal force and

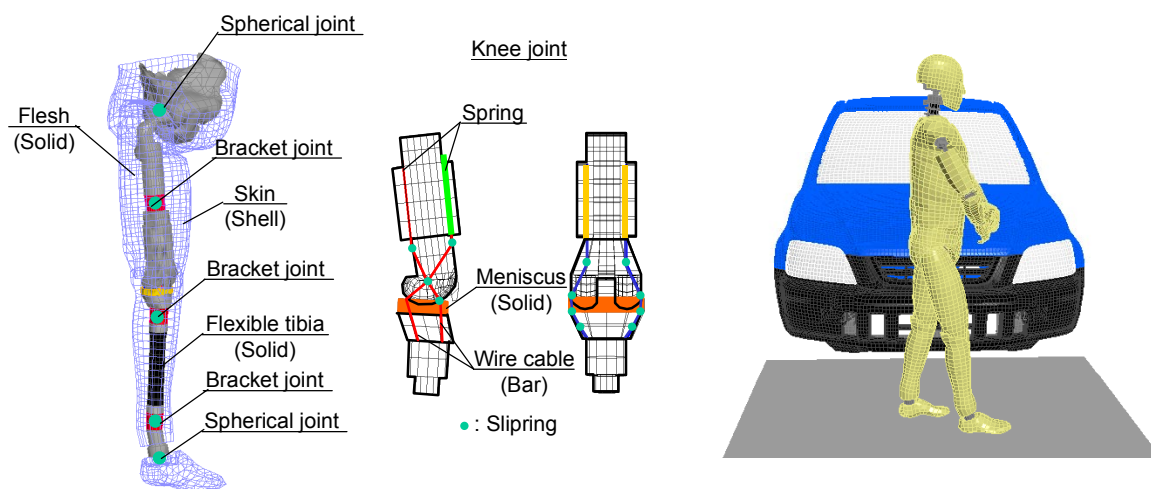
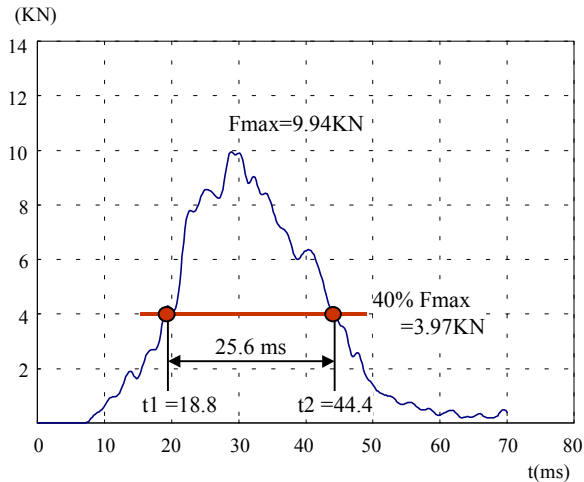


Figure 10. Structure of POLAR lower limb model and overall view of calculation model



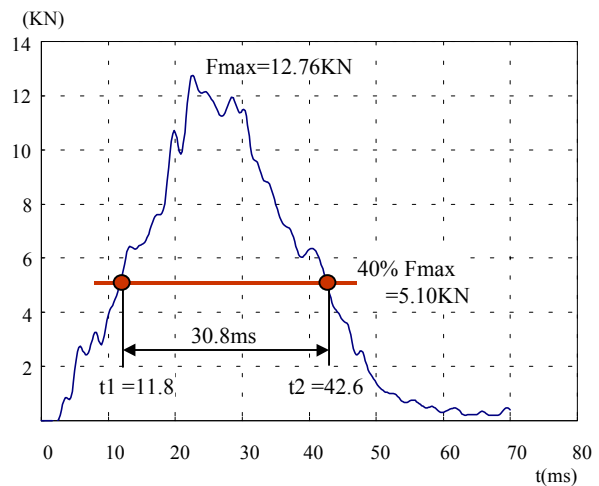
**Figure 11. Addition of contact force pelvis - bonnet and femur - grill and bonnet**

penetration to the femur angle because the EEVC legform impactor has a normal guide to the upper legform. ( Konosu method ) The pelvis angle can be determined by the simulation result, but the lower part of it moves together with femur, so the femur angle is used.

- (3) Energy is calculated with the contact force of the pelvis and femur and the penetration of the pelvis. The pelvis and femur is considered to the one component and the pelvis stroke is more influential in the deformation of the B.L.E..
- (4) The femur contact force with the bumper is excluded for the calculation because the upper legform impact test evaluates the B.L.E..

Fig.11 shows the resultant contact force time history from the simulation.

From this simulation result, estimated energy is 360J. The reconstruction tests are began using this value and the results show the acceptable energy is



**Figure 12. Addition of contact force pelvis - bonnet and femur - bumper, grill and bonnet**

around 400J (Table 5). From EEVC WG17 look-up graph test energy is 1095J which is around 2.5 times the reconstruction test result. To consider the difference between the look-up graph and the reconstruction test result, other estimations are conducted with the simulation results:

- (1) Femur contact force from the bumper either included or not.
- (2) Impact force and penetration is adopted either normal to the femur angle or resultant value.

Figure 12. shows the resultant contact force time history including the contact force from the bumper. Table 6. shows the results of each estimation. From Table 6., the EEVC look-up graph level is similar to the case used the resultant impact force and penetration. The estimated energy with the reconstruction test result is around 400J that is similar to the simulation result with the impact force and penetration normal to the femur angle. So the energy should be estimated with

**Table 6. Energy estimation for each case**

Case No.	Contact Force			Component of force and penetration		Period for estimation ( t1 - t2 )	Estimated Energy ( J )
	Pelvis	Femur		Normal to femur angle	Resultant		
	- Bonnet	- Bonnet - Grill	- Bonnet - Grill - Bumper				
1	●	●		●		●	360
2	●	●			●	●	1393
3	●		●	●		●	477
4	●		●		●	●	1713

the normal force and penetration to the femur angle.

## CONCLUSION

Pedestrian accident data where the injury source is the bonnet leading edge is analyzed and the crash test with the POLAR pedestrian dummy is conducted. The comparison between those results and EEVC WG17 upper legform impact test is studied. The conclusions are summarized below.

- (1) Because the main injury part for the bonnet leading edge of the utility vehicle is the pelvis, the evaluation measurement in EEVC WG17 upper legform impact test should consider only the impact force for utility vehicles.
- (2) The impact test energy in the look-up graph of EEVC WG17 is more severe than the result of the crash test with the POLAR pedestrian dummy. Considering the construction of the test device (with guide), the test energy in EEVC WG17 upper legform impact test should be decreased.

## ACKNOWLEDGEMENT

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